

DESY 94-008

January 1994

# Do Deep Inelastic Scattering Data Favor a Light Gluino?

Johannes Blümlein and James Botts

*DESY-Institut für Hochenergiephysik,  
Platanenallee 6, D-15735 Zeuthen, FRG*

## Abstract

A next-to-leading order QCD analysis of deep inelastic scattering data is performed allowing for contributions due to a light gluino. We obtain the values of  $\alpha_s(M_Z^2) \pm \delta\alpha_s^{stat} = 0.108 \pm 0.002, 0.124 \pm 0.001, 0.145 \pm 0.009$  for QCD, SUSY QCD with a Majorana gluino and a Dirac gluino respectively. The value of  $\alpha_s(M_Z^2)$  obtained in SUSY QCD with a Majorana gluino best agrees with the direct measurements of  $\alpha_s(M_Z^2)$  at LEP.

The most precise measurements of  $\alpha_s(Q^2)$  are provided by deep inelastic lepton–hadron scattering and  $e^+e^-$  experiments and extend over many generations of scale providing a test of QCD [1]. The results of the QCD analyses performed in the different deep inelastic scattering experiments may be expressed in terms of a value for  $\alpha_s(M_Z^2)$  (by a next-to-leading order (NLO) relation, for example) and thus directly compared with the results obtained in  $e^+e^-$  experiments at LEP. Different values of  $\alpha_s(M_Z^2)$  are obtained from deep inelastic and  $e^+e^-$  experiments. The question has arisen whether this difference might be due to the presence of a light gluino [2, 3] for which windows remain open in the range  $m_{\tilde{g}} \lesssim 5 \text{ GeV}$  [4, 5]<sup>1</sup>.

Unlike direct measurements of  $\alpha_s(M_Z^2)$  in LEP experiments, the QCD analysis of deep inelastic scattering data requires an assumption on the  $\beta$ -function to solve the evolution equations. As shown in [3] the re-evaluation of  $\alpha_s(M_Z^2)$  resulting from the DIS-data under the assumption of the NLO  $\beta$ -function in the presence of a light Majorana gluino [9] yields a better agreement with data.

However, the effect of a light gluino in the mass range  $m_{\tilde{g}} \lesssim 5 \text{ GeV}$  on the scaling violations of structure functions is *not only* due to a modification of the  $\beta$ -function, but also due to modified evolution equations containing even different parton densities. Since the allowed gluino mass is rather small, a thorough study of this effect requires a complete NLO QCD analysis of the deep inelastic data including light gluinos<sup>2</sup>. This is the purpose of the present paper.

## The Running Coupling Constant

Before we study the evolution of deep inelastic structure functions we summarize the effect of a gluino on  $\alpha_s(Q^2)$ . The renormalization group equation for  $\alpha_s$

$$\frac{\partial \alpha_s}{\partial \log \mu^2} = -\frac{\beta_0}{4\pi} \alpha_s^2 - \frac{\beta_1}{(4\pi)^2} \alpha_s^3 - \frac{\beta_2}{(4\pi)^3} \alpha_s^4 + \dots \quad (1)$$

yields the solution

$$\frac{1}{\alpha_s(Q^2)} = \frac{1}{\alpha_s(Q_0^2)} + \frac{\beta_0}{4\pi} \log \left( \frac{Q^2}{Q_0^2} \right) + \Phi^{(n)}(\alpha_s(Q^2); \beta_i) - \Phi^{(n)}(\alpha_s(Q_0^2); \beta_i) \quad (2)$$

with the function<sup>3</sup>  $\Phi^{(n)}(x; \beta_i)$  having the form in next-to-next to leading order (NNLO)

$$\begin{aligned} \Phi^{(n)}(x; \beta_i) &= -\frac{\beta_1}{8\pi\beta_0} \ln \left| \frac{16\pi^2 x^2}{16\pi^2 \beta_0 + 4\pi\beta_1 x + \beta_2 x^2} \right| \\ &+ \frac{\beta_1^2 - 2\beta_0\beta_2}{8\pi\beta_0 \sqrt{4\beta_2\beta_0 - \beta_1^2}} \arctan \left( \frac{2\pi\beta_1 + \beta_2 x}{2\pi \sqrt{4\beta_0\beta_2 - \beta_1^2}} \right) + \mathcal{O}(\beta_3) \end{aligned} \quad (3)$$

---

<sup>1</sup>Different possibilities for a dedicated search for light gluinos have been also proposed in [2, 6, 7] recently. Light gluinos are also favored in some approaches in string theory (see [8]).

<sup>2</sup>The effect of a gluino with  $m_{\tilde{g}} \sim 5 \text{ GeV}$  on data expected in the *high*  $Q^2$  range at HERA, decoupling at low  $Q^2$  range, was studied in [7] in LO recently.

<sup>3</sup>Because the explicit expression for (3) depends on the size of  $\beta_{0,1,2,\dots}$   $\Phi^{(n)}(x; \beta_i)$  is understood to be a complex valued function.

In the limit  $\beta_2 \rightarrow 0$  (NLO) one obtains

$$\Phi^{(1)}(x; \beta_i) = -\frac{\beta_1}{4\pi\beta_0} \ln \left[ \frac{\beta_0^2 x}{4\pi\beta_0 + \beta_1 x} \right] + C \quad (4)$$

where we choose  $C = 0$  following [10]<sup>4</sup>. The coefficients  $\beta_i$  are given by [12, 9]

$$\begin{aligned} \beta_0 &= 11 - \frac{2}{3}N_f - 2N_{\tilde{g}} \\ \beta_1 &= 102 - \frac{38}{3}N_f - 48N_{\tilde{g}} \\ \beta_2 &= \frac{2857}{2} - \frac{5033}{18}N_f + \frac{325}{54}N_f^2 + \tilde{\beta}_{2,\tilde{g}}(N_f, N_{\tilde{g}}) . \end{aligned} \quad (5)$$

$\tilde{\beta}_{2,\tilde{g}}(N_f, N_{\tilde{g}})$  describes the gluino contribution to  $\beta_2$ .  $N_f$  denotes the number of active quark flavours and  $N_{\tilde{g}} = 0, 1, 2$  refers to QCD, supersymmetric QCD with Majorana gluinos, and Dirac gluinos, respectively. Eq. (2) can be solved iteratively. If  $\alpha_s(Q_0^2)$  is chosen by  $\alpha_s(M_Z^2)$  one can calculate  $\alpha_s(Q^2)$  as a function of  $\beta_0$  and  $\beta_1$ , and the dependence on  $\Lambda$  is implicit only through  $\alpha_s(Q_0^2)$ . The  $\Lambda$  dependence can be made explicit through the definition

$$\Lambda := Q_0 \exp \left\{ -\frac{2\pi}{\beta_0\alpha_s(Q_0^2)} + \frac{\beta_1}{2\beta_0^2} \log \left[ \frac{\beta_0^2\alpha_s(Q_0^2)}{4\pi\beta_0 + \beta_1\alpha_s(Q_0^2)} \right] \right\} \quad (6)$$

in the  $\overline{\text{MS}}$  scheme in NLO<sup>5</sup>. Eq. (6) relates the values of  $\Lambda$  and  $\alpha_s$  at a given scale *directly*.

When quark or gluino mass-thresholds  $\mu \approx 2m_i$  are passed,  $\alpha_s(Q^2)$  is kept continuous as the values of  $\beta_i$  change. To be more precise, running mass effects should be accounted for when passing quark or gluino mass thresholds [13]. We will neglect these effects in the present analysis as small<sup>6</sup>.

In figure 1 a comparison of the NLO solutions (2) using  $\alpha_s(Q_0^2) = \alpha_s(M_Z^2) = 0.122$  for  $N_{\tilde{g}} = 0, 1, 2$ ,  $m_{\tilde{g}} = 0, 3, 5$  GeV, and different measurements of  $\alpha_s$  is shown. Here we assumed  $m_c = 1.6$  GeV and  $m_b = 4.75$  GeV for the values of the heavy quark masses. For the case of QCD also the curve obtained in NNLO is given. That a light Majorana gluino is an apparently better description of  $\alpha_s(Q^2 > 16 \text{ GeV}^2)$  than QCD has been previously observed in [3]. Calculating confidence levels for the depicted experimental data in the complete  $Q^2$  range<sup>7</sup> from the  $\chi^2$  values for the three different hypothesis  $N_{\tilde{g}} = 0, 1, 2$ , however, one obtains 78 % CL for QCD, 50–83 % CL for the case of a Majorana gluinos ( $0 < m_{\tilde{g}} < 5$  GeV), and  $< 0.5$  % CL for the case of a Dirac gluino. This estimate, however, assumes, that the  $\alpha_s$  values have been extracted in a way which is essentially insensitive to the value of  $N_{\tilde{g}}$ , since most of these values were obtained using QCD matrix elements as an input.

## QCD Analysis

Scaling violations of the structure functions measured in different deep inelastic scattering

<sup>4</sup> This choice is often called definition of  $\alpha_s(Q^2)$  in the  $\overline{\text{MS}}$  scheme, although  $\beta_{0,1}$  are scheme independent and only  $\beta_2$  eq. (5) refers to a  $\overline{\text{MS}}$  result. Other possible choices are discussed in [11].

<sup>5</sup> A corresponding relation in NNLO follows from (2,3) directly.

<sup>6</sup> As has been shown recently [14] this modification leads to a shift  $\Delta\alpha_s(M_Z^2) \sim 0.001$  unless a quark mass threshold coincides with that of the gluino.

<sup>7</sup> The  $\alpha_s$  value determined from  $c\bar{c}$   $1P - 1S$  mass splitting using a lattice calculation [15] was excluded.

experiments can be described<sup>8</sup> by the following set of NLO evolution equations including the effect of a light gluino,

$$\begin{aligned} \frac{d}{dt} q_i^{(-)}(t, x) &= \left[ P_{NS}^{(0)}(x) + \frac{\alpha_s(t)}{2\pi} \tilde{P}_{NS,-}^{(1)}(x) \right] \otimes q_i^{(-)}(t, x) \\ \frac{d}{dt} \tilde{q}_i^{(+)}(t, x) &= \left[ P_{NS}^{(0)}(x) + \frac{\alpha_s(t)}{2\pi} \tilde{P}_{NS,+}^{(1)}(x) \right] \otimes \tilde{q}_i^{(+)}(t, x) \\ \frac{d}{dt} \begin{bmatrix} q^{(+)}(t, x) \\ G(t, x) \\ \tilde{g}(t, x) \end{bmatrix} &= \left[ \mathbf{P}^{(0)}(x) + \frac{\alpha_s(t)}{2\pi} \mathbf{R}(x) \right] \otimes \begin{bmatrix} q^{(+)}(t, x) \\ G(t, x) \\ \tilde{g}(t, x) \end{bmatrix}. \end{aligned} \quad (7)$$

The gluino density  $\tilde{g}(t, x)$  emerges in the singlet evolution equation. In the description of the singlet and non-singlet distributions we assume that the squark contributions decouple [17] due to the current experimental limit  $m_{\tilde{q}} > 74 \text{ GeV}$  [4]. The functions

$$R_{\pm}(x) = P_{NS,\pm}^{(1)}(x) - \frac{\beta_1}{2\beta_0} P_{NS}^{(0)}(x) \quad (8)$$

$$\mathbf{R}(x) = \mathbf{P}^{(1)}(x) - \frac{\beta_1}{2\beta_0} \mathbf{P}^{(0)}(x) \quad (9)$$

are expressed by the splitting functions  $P^{(k)}(x)$  up to NLO. Note, that the leading order matrix elements  $P_{qg}^{(0)}(x)$  and  $\tilde{P}_{gq}^{(0)}(x)$  of  $\mathbf{P}^{(0)}(x)$  vanish.

The different combinations of quark densities in (7) are

$$\begin{aligned} q_i^{(\pm)}(t, x) &= q_i(t, x) \pm \bar{q}_i(t, x) \\ q^{(+)}(t, x) &= \sum_{i=1}^{N_f} q_i^{(+)}(t, x) \\ \tilde{q}_i^{(+)}(t, x) &= q_i^{(+)}(t, x) - \frac{q^{(+)}(t, x)}{N_f}. \end{aligned} \quad (10)$$

The evolution variable is  $t = -(2/\beta_0) \log[\alpha_s(Q^2)/\alpha_s(Q_0^2)]$ , with  $Q_0$  defining the scale at which the input distributions  $q_i^{(\pm)}(x, Q_0^2)$ ,  $G(x, Q_0^2)$ , and  $\tilde{g}(x, Q_0^2)$  are parametrized.  $\otimes$  describes the Mellin convolution.

The splitting functions  $P_{ij}^{(k)}(x)$  in (7,8) were given in [18, 19] where in NLO the  $\overline{\text{DR}}$  scheme was used. In the present analysis these results were translated into the  $\overline{\text{MS}}$  scheme.

The QCD analysis was performed with a modified version of the CTEQ parton distribution evolution program [20]. The input shapes for the parton distributions at  $Q_0^2$  were chosen to be

$$\begin{aligned} xu_v(x) &= A_u x^{\alpha_u} (1-x)^{\beta_u} (1+\gamma_u x) \\ xd_v(x) &= A_d x^{\alpha_d} (1-x)^{\beta_d} (1+\gamma_d x) \\ x(\bar{d} + \bar{u})(x) &= A_+ x^{\alpha_+} (1-x)^{\beta_+} (1+\gamma_+ x) \end{aligned}$$

---

<sup>8</sup>The data analysis performed on this basis will include the data currently measured at HERA [16] also. Although these are small  $x$  data they also exhibit logarithmic scaling violations.

$$\begin{aligned}
x(\bar{d} - \bar{u})(x) &= -x^{\alpha_-}(1-x)^{\beta_-}(1 + \delta_- \sqrt{x} + \gamma_- x) \\
xs(x) &= A_s x^{\tilde{\alpha}_s}(1-x)^{\beta_s} \\
xG(x) &= A_G x^{\alpha_G}(1-x)^{\beta_G}(1 + \gamma_G x) \\
x\tilde{g}(x) &= A_{\tilde{g}} x^{\alpha_{\tilde{g}}}(1-x)^{\beta_{\tilde{g}}}
\end{aligned} \tag{11}$$

The sensitivity of the parameters in (11) to the fit results varies, and some of them may be fixed or can be related to one another. The 10-parameter parametrization used in our analysis was the result of a study to minimize the number of shape parameters needed to fit the current set of experimental inclusive data in a global QCD analysis. This is desirable as fewer shape parameters are clearer to analyze and reduce spurious correlations between themselves. We set  $\alpha_u = \alpha_d = 0.5$ ,  $\beta_u = 4.0$ ,  $\beta_d = 3.0$ ,  $\beta_+ = \beta_- \equiv \beta_G + 1$ ,  $\alpha_+ \equiv \alpha_G$ , and  $\gamma_+ \equiv \gamma_G$ . The sum rules  $\int_0^1 u_v(x)dx = 2$ ,  $\int_0^1 xd_v(x)dx = 1$ , and momentum conservation reduce by three the number of input fitting parameters. The parameters of the strange quark distribution have been determined from the CCFR dimuon data [21] as  $A_s = 0.114$ ,  $\tilde{\alpha}_s = -0.114$ , and  $\beta_s = 6.87$  and are treated as fixed. Only for  $m_{\tilde{g}} \leq Q_0 \equiv 1.6$  GeV do we have an initial three parameter nonzero gluino distribution. Otherwise the gluino distribution was radiatively generated as were the heavy flavor distributions.

We allowed the relative normalizations of the different experimental data sets (seven parameters) to float under the fit subject to suitable constraints reflecting experimental normalization uncertainty in the mean.

$\Lambda$  and the parameters of eq. (11) were determined by a MINUIT [22] minimization of a  $\chi^2$ -distribution using the following data sets: SLAC  $F_2^{ep}, F_2^{ed}, F_2^{ed}/F_2^{ep}$ , NMC  $F_2^{\mu d}, F_2^{\mu p}, F_2^{\mu n}/F_2^{\mu p}$  for  $E_\mu = 90$  and 280 GeV, BCDMS  $F_2^{\mu d}, F_2^{\mu p}$ , CCFR  $F_2^\nu, xF_3^\nu$ , and ZEUS and H1  $F_2^{ep}$  [23, 16] as input. The statistical and systematical experimental errors were added in quadrature, and relative systematic effects between the different experiments were accounted for by normalization factors determined in the fit. For a given gluino mass hypothesis it was demanded, that  $W^2 = Q^2(1-x)/x > 4m_{\tilde{g}}^2$  leading to a constraint on the data used. For the comparison of different possible hypotheses we considered the cases  $N_{\tilde{g}} = 0$  (QCD), and  $N_{\tilde{g}} = 1, 2$  with  $m_{\tilde{g}} = 0, 3$ , and 5 GeV. Table 1 summarizes the results on  $\Lambda$  and  $\alpha_s(M_Z^2)$  and table 2 contains the shape parameters determined for some characteristic cases and the fitted relative normalizations of the different data sets used in the analysis. The latter parameters values differ by only up to 5 % from unity. Note, that the values of  $\Lambda_{\overline{\text{MS}}}^{(5)}$  (the value above the  $b$ -quark threshold) and  $\alpha_s(M_Z^2)$  given in table 1 are directly related by eq. (6) and no reference to a "typical" value of  $\langle Q^2 \rangle$  characterizing the analysed data sets is needed<sup>9</sup>.

## Discussion

The values of  $\chi^2/\text{NDF}$  obtained in the analysis of all the deep inelastic scattering data do not differ significantly (see table 1). Thus, the analysis does not yield an a priori preference to one of the cases  $N_{\tilde{g}} = 0, 1, 2$ . The fitted values of  $\Lambda_{\overline{\text{MS}}}^{(5)}$  are expressed in terms of  $\alpha_s(M_Z^2)$  in table 1.  $\alpha_s(M_Z^2)$  allows a more direct comparison of the different results, because  $M_Z \gg m_b, m_{\tilde{g}}$ . Besides the quoted statistical error  $\delta\alpha_s^{\text{stat}}$ , there is a theory error due to the assumption on

---

<sup>9</sup>Such an assumption would be required for an illustration of the obtained result in the way shown in figure 1, but will not be given due to the uncertainty in the abscissa.

the factorization scale [24],  $\delta\alpha_s(M_Z^2)^{theor}$ , which has been estimated to be  $\approx 0.005$ . This error dominates the statistical error determined by the analysis. From direct measurements at LEP one obtains  $\alpha_s(M_Z^2) = 0.122 \pm 0.006$  [1b]. Comparing the results on  $\alpha_s(M_Z^2)$  given in table 1 with the LEP result, we derive the confidence levels of 8 %, 70 %, and 5 % for the hypotheses  $N_{\tilde{g}} = 0, 1$ , and 2, respectively, for the agreement of both values. Here  $\delta\alpha_s^{theor} = 0.005$  was added to the corresponding statistical errors in quadrature in the definition of  $\chi^2$ .

The resulting up quark, gluon and gluino distributions at  $Q^2 = 10 \text{ GeV}^2$  and  $100 \text{ GeV}^2$  of QCD, SUSY QCD with a massless, 3 and 5 GeV gluino are shown in Fig. 2a–f. The distributions  $u_{SUSY}(x)$  and  $g_{SUSY}(x)$  are softer at  $Q^2 \leq 10 \text{ GeV}^2$ , the faster running coupling of QCD compensating for the initial depletion of larger  $x$  distributions in the SUSY case. At small  $x$ ,  $x < .01$ , the sea and gluon distributions in the SUSY case are enhanced by the splitting of larger  $x$  gluinos.

The fit results are not very sensitive to the parameters of the gluino distribution and allow large distributions at small  $x$  where the data is not yet very precise however. The gluino distribution is forced by the evolution equations to behave like a sea quark, the existing DIS data forces it to be quite soft. The magnitude of the gluino distribution is strongly dependent on  $m_{\tilde{g}}$  over a large range of  $Q^2$ , the dependence decreases logarithmically with increasing scale.

If Majorana gluinos exist in the mass range  $m_{\tilde{g}} < 5 \text{ GeV}$ , they can be searched for in single and pair production in deep inelastic  $ep$ -scattering and photoproduction at HERA. The process of single gluino production will moreover allow the derivation of direct constraints on the gluino distribution.

## Acknowledgements

The authors would like to thank the members of the *CTEQ* collaboration, especially Wu-Ki Tung, for sharing their expertise in QCD global analysis of parton distributions.

## References

- [1] G. Altarelli, in Proc. of the International Workshop, 'QCD – 20 Years Later', Aachen 1992, eds. H.A. Kastrup and P.M. Zerwas, (World Scientific, Singapore, 1993), p. 172; S. Bethke, HD-PY-93-07, Lecture at the 42nd Scottish Universities Summer School in Physics, St. Andrews, Scotland, August 1993; S. Catani, Florence preprint DFF-194-11-93, to appear in: Proc. of the 1993 Int. Europhysics Conf. on High Energy Physics, Marseille.
- [2] J. Ellis, D.V. Nanopoulos, and D.A. Ross, Phys. Lett. **B305** (1993); I. Antoniadis, J. Ellis, and D.V. Nanopoulos, Phys. Lett. **B262** (1991) 109.
- [3] M. Jezabek and J.H. Kühn, Phys. Lett. **B301** (1993) 121.
- [4] Particle Data Group, K. Hikasa et al., Phys. Rev. **D45**, No. 11, II.34, IX.5.
- [5] UA1 Collaboration, C. Albajar et al., Phys. Lett. **198** (1987) 261; see also: L. Clavelli, Phys. Rev. **D45** (1992) 3276; **D46** (1992) 2112; Univ. of Alabama preprint UAHEP 9216; L. Clavelli, P.W. Coulter, and K. Yuan, Phys. Rev. **D47** (1993) 1973; L. Clavelli, P.H. Cox, and K. Yuan, Univ. of Alabama preprint UAHEP-9211 (1992); L. Carena, L. Clavelli, D. Matalliotakis, H.P. Nilles, and C.E.M. Wagner, Phys. Lett. **B317** (1993) 346.
- [6] J.L. Lopez, D.V. Nanopoulos, and Xu Wang, Phys. Lett. **B313** (1993) 241; R. Munoz-Tapia and W.J. Stirling, Durham preprint DTP-93-72; G. Bhattacharyya and A. Raychaudhuri, Phys. Rev. **D47** (1993) 2014; CUPP-93-4; F. De Campos and J.W.F. Valle, FTUV-93-9A; F. Cuypers, Munich preprint LMU-09-93; MPI-Ph/93-69; C.E. Carlson and M. Sher, Williamsburg preprint WM-93-114.
- [7] R.G. Roberts and W.J. Stirling, Phys. Lett. **B313** (1993) 453.
- [8] A. Font, L.E. Ibáñez, D. Lust, and F. Quevedo, Phys. Lett. **B245** (1990) 401; L.E. Ibáñez and D. Lust, Nucl. Phys. **B382** (1992) 305.
- [9] S. Dimopoulos, S. Raby, and F. Wilczek, Phys. Rev. **D 24** (1981) 1681; L.E. Ibáñez and G.G. Ross, Phys. Lett. **B105** (1981) 439; W.I. Marciano and G. Senjanovic, Phys. Rev. **D25** (1982) 3092; M.B. Einhorn and D.R.T. Jones, Nucl. Phys. **B196** (1982) 475.
- [10] W.A. Bardeen, A.J. Buras, D.W. Duke, and T. Muta, Phys. Rev. **D18** (1978) 3998.
- [11] P.M. Stevenson, Phys. Rev. **D23** (1981) 2916; D.W. Duke and R.G. Roberts, Phys. Rep. **120** (1985) 275 and references therein.
- [12] W. Caswell, Phys. Rev. Lett. **D33** (1974) 244; D.R.T. Jones, Nucl. Phys. **B75** (1974) 531; O.V. Tarasov, A.A. Vladimirov, and A.Y. Zharkov, Phys. Lett. **B93** (1980) 429.

- [13] H. Georgi and H.D. Politzer, Phys. Rev. **D14** (1976) 1829;  
T. Yoshida and K. Hagiwara, Z. Phys. **C24** (1984) 185.
- [14] D.V. Shirkov and S.V. Mikhailov, Bielefeld preprint, BI-TP 93/75, January 1994.
- [15] A.X. El-Khadra, G. Hockney, A.S. Kronfeld, and P.B. Mackenzie, Phys. Rev. Lett. **69** (1992) 729.
- [16] M. Derrick et al., ZEUS collaboration, Phys. Lett. **B316** (1993) 412;  
I. Abt et al., H1 collaboration, Nucl. Phys. **B407** (1993) 515.
- [17] K. Symanzik, Comm. Math. Phys. **34** (1973) 7;  
T. Appelquist and J. Carrazone, Phys. Rev. **D11** (1975) 2856. 375.
- [18] B.A. Campbell, J. Ellis, and S. Rudaz, Nucl. Phys. **B198** (1982) 1.
- [19] I. Antoniadis, E. G. Floratos, Nucl. Phys. **B191** (1981) 217;  
I. Antoniadis, C. Kounnas, and R. Lacaze, Nucl. Phys. **B211** (1983) 216.
- [20] CTEQ collaboration, J. Botts et al., Phys. Lett. **B304** (1993) 159.
- [21] A.O. Bazarko et al., CCFR collaboration, NEVIS preprints # 1492, # 1496 (1993).
- [22] F. James and M. Roos, MINUIT, Release 89.12j (1989), CERN Library D506.
- [23] A.C. Benvenuti et al., Phys. Lett. **B223** (1989) 485, 592;  
L.W. Withlow et al., SLAC-PEP-357 (1990);  
P. Amaudruz et al., NMC collaboration, Nucl. Phys. **B371** (1992) 3; Phys. Lett. **B295** (1992) 159;  
S.R. Mishra et al., CCFR collaboration, Nevis preprint # 1459 (1992); W.C. Leung et al., CCFR collaboration, Nevis preprint # 1460 (1992); P.Z. Quintas et al., CCFR collaboration, Nevis preprint # 1461 (1992).
- [24] A.D. Martin, W.J. Stirling, and R.G. Roberts, Phys. Lett. **B266** (1991) 173;  
M. Virchaux and A. Milsztajn, Phys. Lett. **B274** (1992) 221;  
A. Milsztajn, Nucl. Phys. **B** (Proc. Suppl.) **29A** (1992) 9.



$N_{\tilde{g}}$	$m_{\tilde{g}}/\text{GeV}$	$\chi^2$	$N_{data\ points}$	$\chi^2/\text{NDF}$	$\Lambda_{\overline{\text{MS}}}^{(5)} \pm \delta\Lambda^{stat}$	$\alpha_s(M_Z^2) \pm \delta\alpha_s^{stat}$
0		783	986	0.808	118.0 $\pm$ 13 MeV	0.108 $\pm$ 0.002
1	0	772	986	0.799	7.7 $\pm$ 0.65 MeV	0.124 $\pm$ 0.001
1	3	772	986	0.797	7.7 $\pm$ 0.61 MeV	0.124 $\pm$ 0.001
1	5	544	589	0.951	127.0 $\pm$ 4.7 MeV	0.125 $\pm$ 0.001
2	0	770	986	0.797	3.7 $\pm$ 2.5 keV	0.145 $\pm$ 0.003
2	3	786	986	0.811	7.7 $\pm$ 6.5 keV	0.153 $\pm$ 0.009
2	5	538	589	0.941	123.0 $\pm$ 12 MeV	0.145 $\pm$ 0.009

Table 1: Results of the QCD analysis for  $\Lambda$  and  $\alpha_s(M_Z^2)$

Parameters	QCD	Majorana gluino	
		$m_{\tilde{g}} = 0$	$m_{\tilde{g}} = 3 \text{ GeV}$
$\gamma_u$	2.120	2.061	2.084
$\gamma_d$	-1.167	-1.344	-1.292
$A_G$	0.4742	0.4716	0.4709
$\alpha_G$	-0.3467	-0.3470	-0.3519
$\beta_G$	6.708	6.647	6.636
$\gamma_G$	2.975	2.922	2.962
$\alpha_-$	1.407	1.326	1.351
$\delta_-$	26.42	19.71	21.72
$\gamma_-$	-22.90	-15.13	-17.64
$A_{\tilde{g}}$	•	0.2137	•
$\alpha_{\tilde{g}}$	•	0.0001	•
$\beta_{\tilde{g}}$	•	11.34	•
relative normalizations			
SLAC	1.002	0.998	0.999
NMC $\sqrt{s} = 90 \text{ GeV}$	1.004	1.003	1.003
NMC $\sqrt{s} = 280 \text{ GeV}$	1.016	1.010	1.013
BCDMS	0.984	0.978	0.981
CCFR	0.971	0.966	0.967
ZEUS	1.010	1.002	1.004
H1	0.961	0.952	0.956

Table 2: Results of the QCD analysis for the parameters of the input distributions at  $Q_0^2 = 2.56 \text{ GeV}^2$

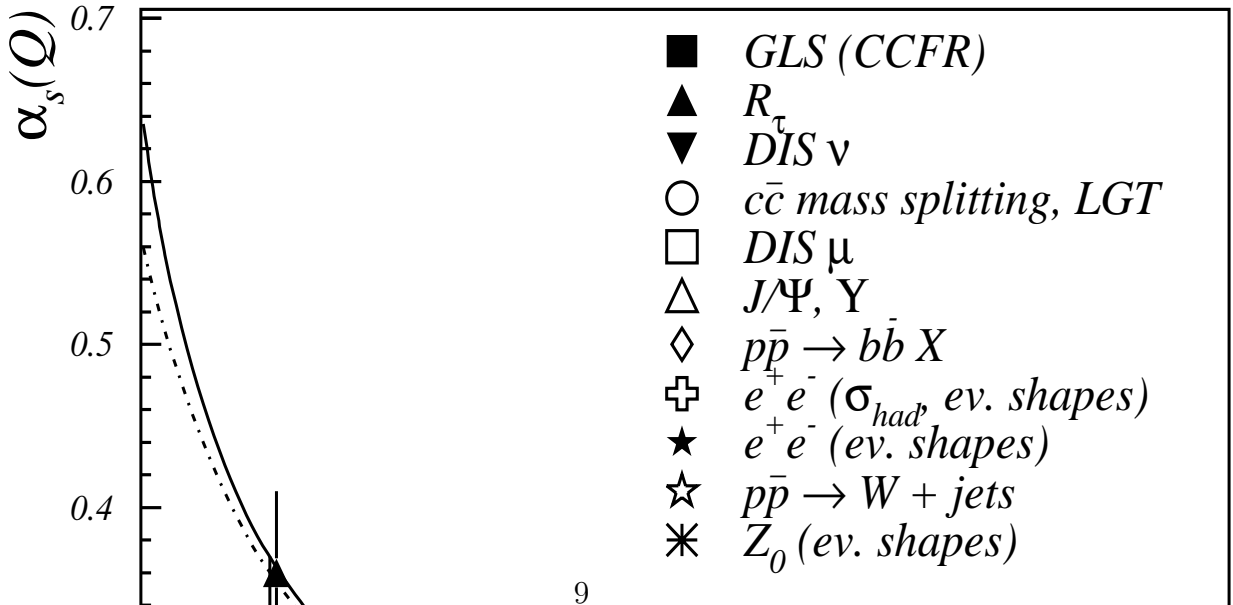


Figure 1: Comparison of different theoretical predictions for  $\alpha_s(Q^2)$  with experimental results of  $\alpha_s$  [1]. The full curves denote the NLO solution of eq. (2) for  $N_{\tilde{g}} = 0, 1, 2$  with  $m_{\tilde{g}} = 0$  taking  $\alpha_s(Q_0^2) = \alpha_s(M_Z^2) = 0.122$ . The dash-dotted line denotes the NNLO solution in the case of QCD. The dashed and dotted lines describe the cases  $m_{\tilde{g}} = 3$  and  $5 \text{ GeV}$ , respectively.

a)

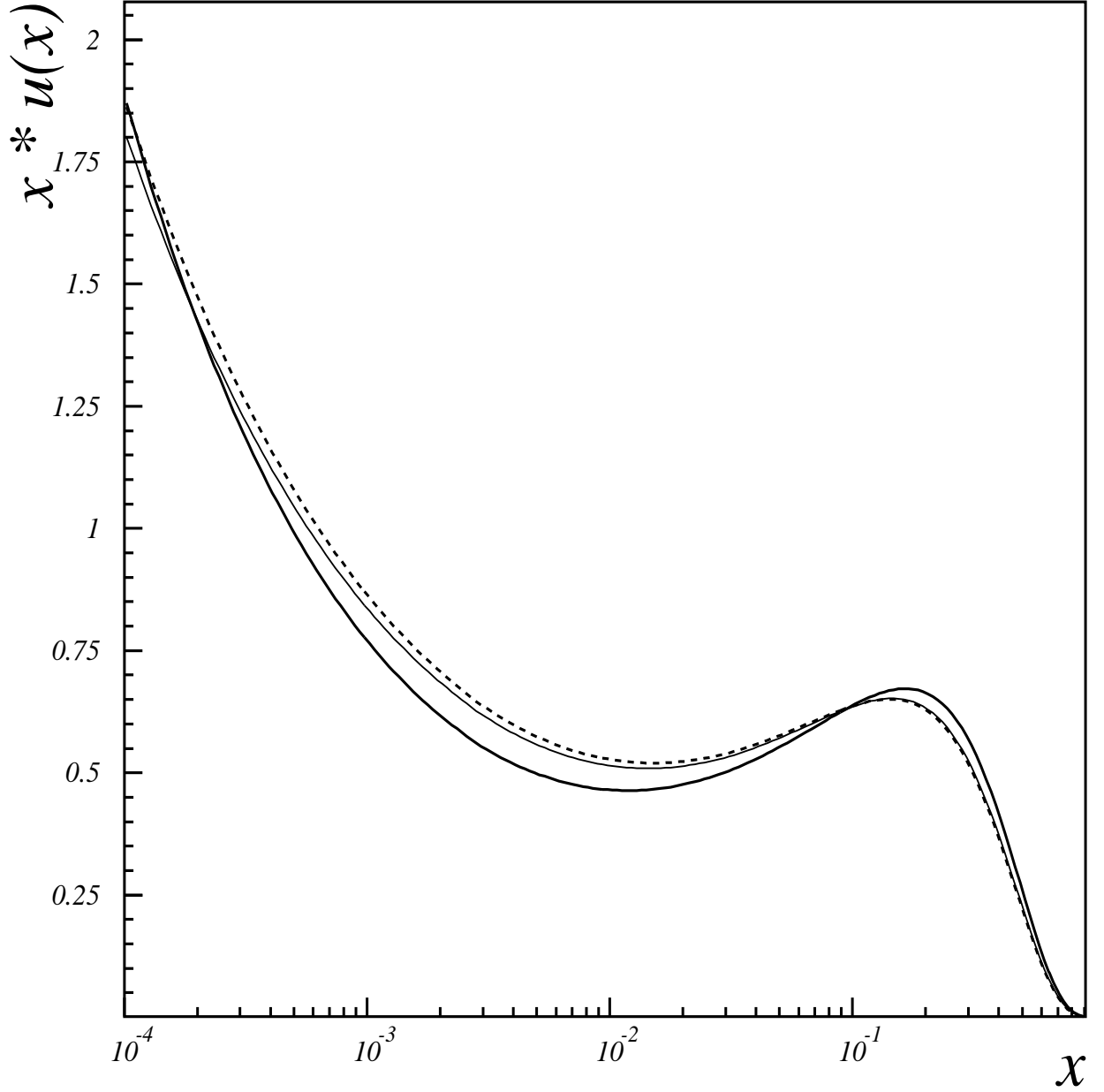
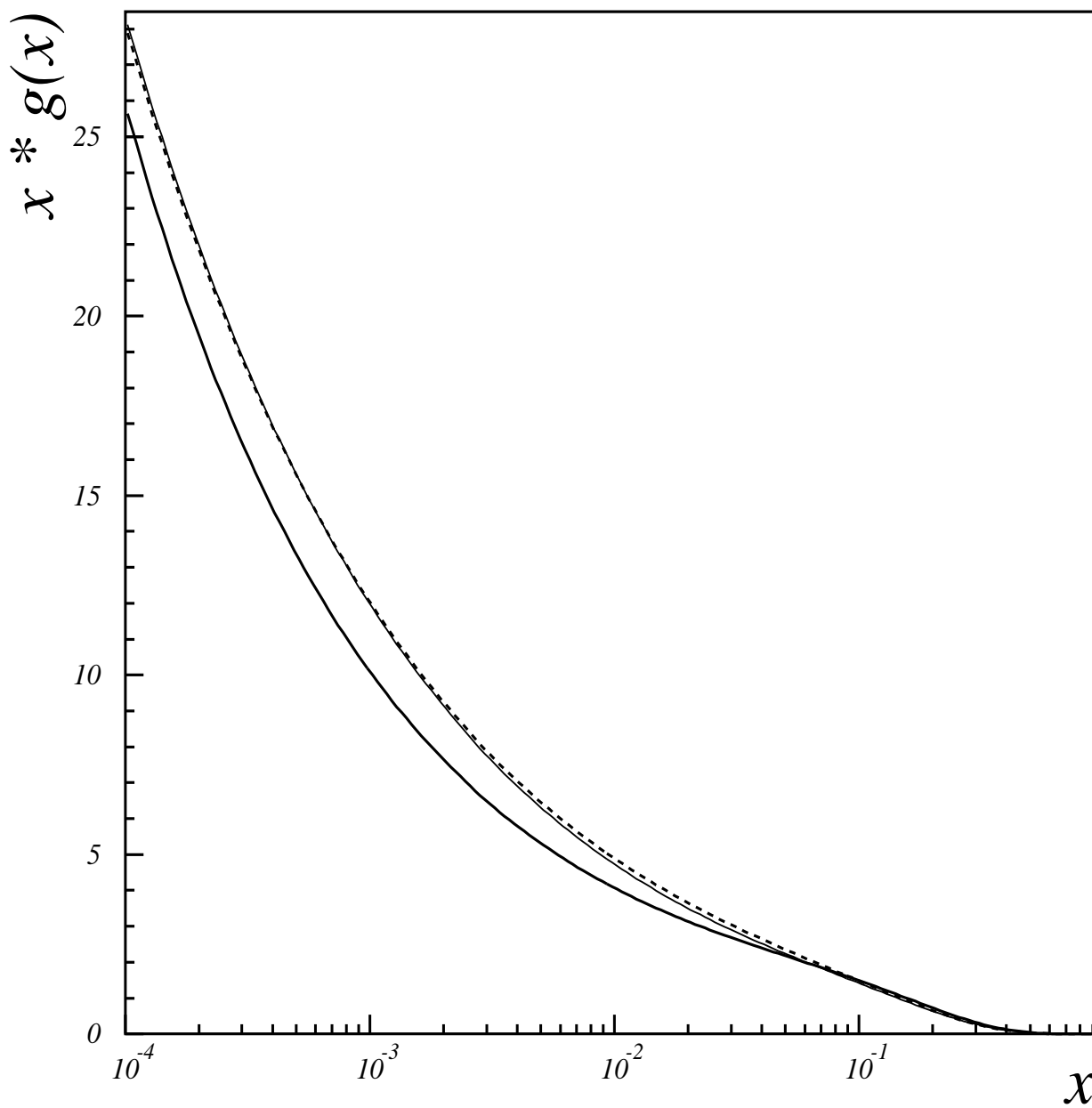
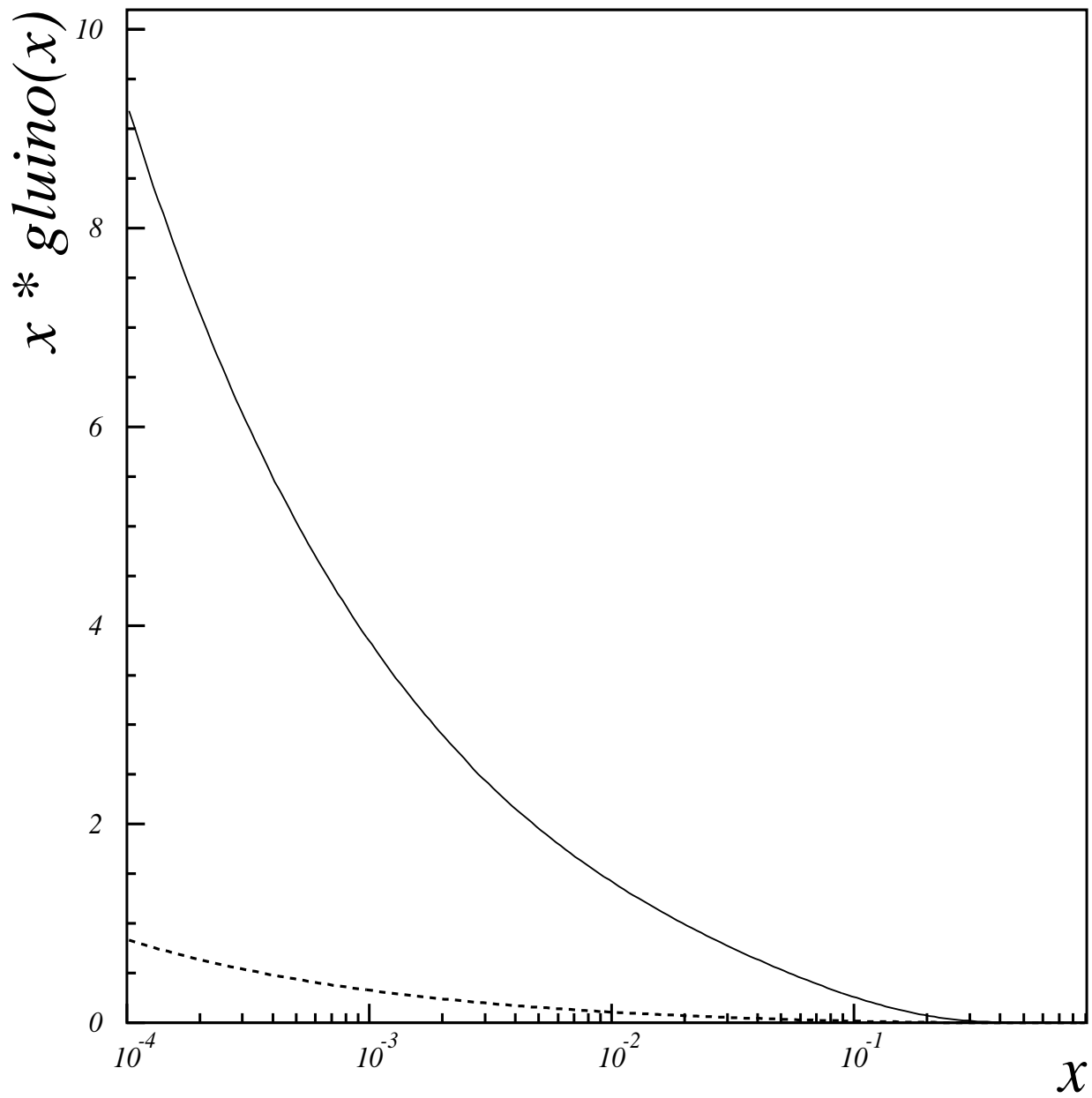


Figure 2: Fit results for the parton distributions. a)  $xu(x, Q^2)$ , b)  $xG(x, Q^2)$ , c)  $\tilde{g}(x, Q^2)$  for  $Q^2 = 10 \text{ GeV}^2$ . The thick solid, thin solid and dashed lines denote QCD, SUSY QCD with a massless Majorana gluino and SUSY QCD with a Majorana gluino of  $m_{\tilde{g}} = 3 \text{ GeV}$  respectively. d)–f) are same as a)–c) with  $Q^2 = 100 \text{ GeV}^2$ . The dotted line denotes SUSY QCD with a Majorana gluino of  $m_{\tilde{g}} = 5 \text{ GeV}$ .

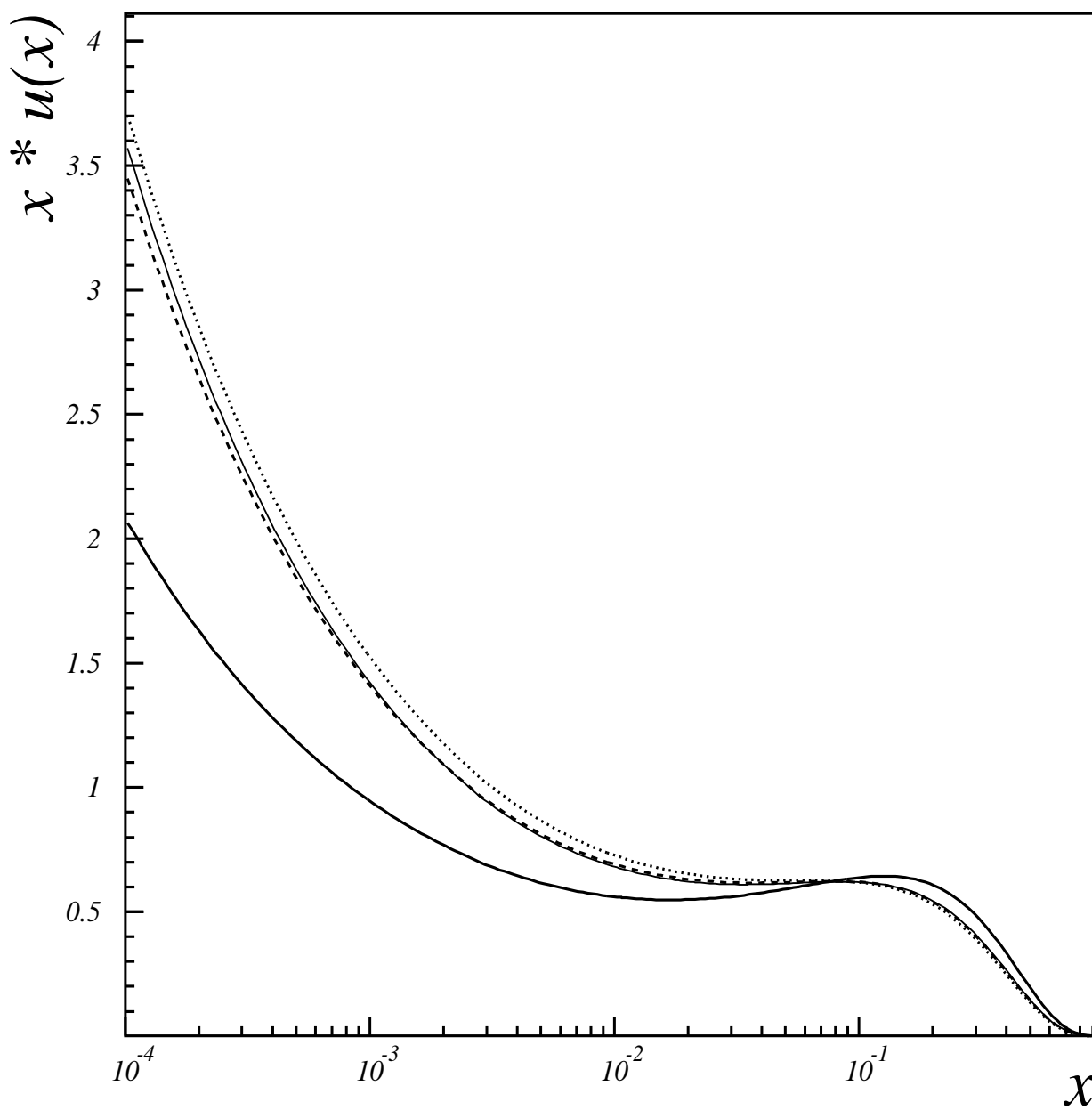
b)



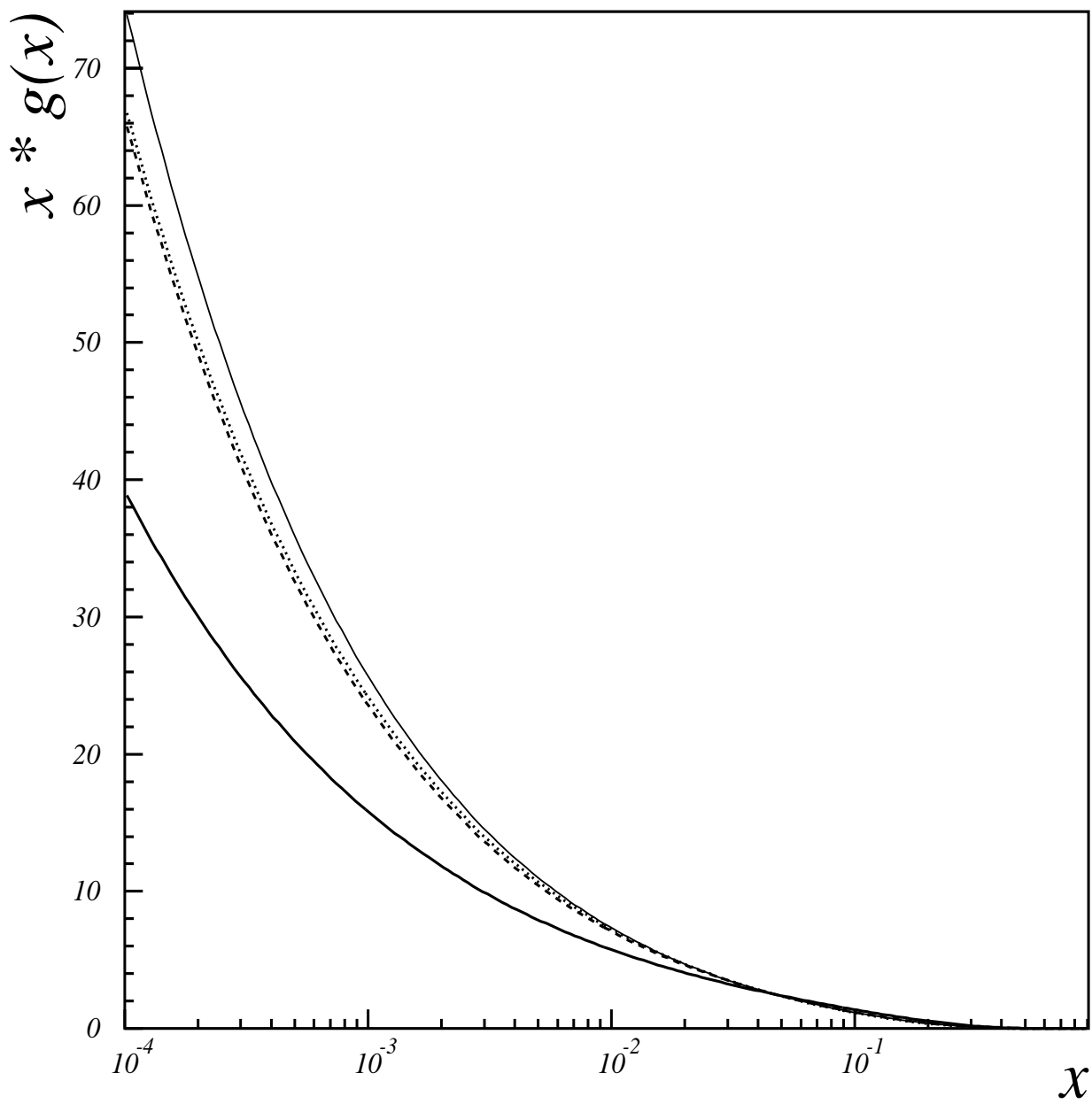
c)



d)



e)





f)

